Questions and Answers about the KamLAND 4pi Calibration System

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Date: *June 8, 2005 11:28:22 AM PDT*
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Cc: *Ron Madaras <RJMadaras@lbl.gov>, Howard Wieman <HHWieman@lbl.gov>*
Subject: ***Re: KamLAND 4pi review***

Hi Karsten, I'll echo Ron's comments - it was a good presentation & demonstration yesterday - it made our jobs much simpler to do - thanks.

I do have a few additional questions. First, from an Equipment safety perspective: In my mind, this device has to be "fail safe" in every regard. It not only has to work and not damage KamLand while it's doing it, but it cannot damage the detector when it fails to operate in it's intended fashion. It appears to me that you've done a lot to address this concern - it was evident in the design. I'm sure you've covered the 1st part (damage the detector during normal operation). I'm looking at a calibration system failure and trying to make sure you've covered every single element of that. Logically, you'd look at each component and try to address what could happen, worst case. So, my list of the bad things that could happen would be:

1) drive system failures (mechanical or motor)
2) cable failures
3) position sensor system failures
4) "top-of-the-triangle" clamp system failure (the one that attaches to one of the cables and allows the other cable to slide)
5) pole/calibration source system failure
6) software/control system failure
7) kind of a catch all - small parts, connectors, fasteners, etc.

I think you've addressed adequately (from my perspective), items 1, 2 5 and perhaps 6. What about 3, 4 & 7? Hopefully these are easy to explain because you've already thought about them too.
a) What backup system(s) do you have for real-time monitoring of the pole position so that you could remove it safely if you lost track of cable position? (maybe this is as easy as you know the length of the two cables so you could always recoup, but to what accuracy and is this enough to withdraw the Pole without damaging anything.)
b) What if the top of triangle clamp system somehow bound up so that the cable that's supposed to slide caught and both cables started moving together? How would you determine this? And, how quickly (how many cm of travel)?
c) Have you looked at each small element like connectors and fasteners and pins

and though about what would happen if they got loose or failed? Any chance of one of these pieces dropping into the balloon and being unrecoverable?

Next, Human safety. I look at this list as:
1) Mechanical hazards (sharp objects, things dropping and hitting someone, gears and things that grab, etc)
2) Electrical/shock hazards
3) fire/smoke/oxygen deficiency hazards
4) Radiation hazards
5) Laser or UV, etc. hazards

a) I think you've covered most of item 1, but what do you think? Sharp edges? What about drop hazards from the 2 person hand off operations? Some of these will have to be handled through written procedures I suppose? Are all gear boxes fully enclosed? What would happen if you stuck your finger in the pulley system (motor torque limit)?
b) Item 2 didn't get covered. Are all the voltages below 50V and low current? If so, you're probably fine.
c) Item 3, you said motors were enclosed (?) and nothing got hot. Are all current carrying cables well insulated? What are chances of shorts causing fires? Are fuse and safety devices set low enough that nothing could get very hot under any circumstances? What about if a drive cable got caught and the motor tried to overcome this - or are the load/torque limits set so low things would shut off?
d) Item 4, I assume all sources are low level? What kind of handling precautions are required (time exposure limits)? How are they stored (locked container with all relevant safety requirements met)? How about shipping/transportation - precautions identified & dealt with?
e) Item 5, you don't have either of these right? Intensity of 830nm IR LED is not a hazard to eyes right?

That's about it for questions - sorry for so many. Please write a very brief (one sentence) response to the simple ones. If it is really obviously not a problem, assume we'll understand why - don't waste your time. Spend a little time thinking and writing a response to the difficult ones though. There is still some more work to be done (materials, survey work, etc.), but you know that and I'm sure we'll try to list these items in the report.

Thanks, - Bill

Response to Bill Edwards' Questions, June 8, 2005

I. Equipment Safety

1) Drive system failures (mechanical or motor)

The motors used in the 4pi deployment system are equipped with an automatic brake that engages as soon as the power to the motors is cut. This serves as a primary safety mechanism for unexpected power outages (beyond the lifetime of the UPS) and other failures. Other mechanical failures of the motor+gears assembly have been considered and are addressed in the emergency recovery procedures. The dimensional constraints of the deployment system and the glovebox make it essentially impossible to exchange or repair the motors without opening the glovebox. Due to the low-background environment in the KamLAND it is undesirable to open the glovebox to ambient air while the 4pi system is deployed. In this case we would consider a manual retraction of the system as outlined here:
http://kmheeger.lbl.gov/kamland/4pi/reviewjune05/4pi_emergencyrecovery.pdf
If this were considered to risky we could secure the system in place with an emergency clamp, make a nitrogen cover blanket for the nylon cable guide, and then open the glovebox to repair the motors or gears. Page 7 in the following document shows how the system can be secured in place in an emergency situation:
http://kmheeger.lbl.gov/kamland/4pi/reviewjune05/4pi_emergencyrecovery.pdf

2) Cable failures

There are several different kind of cable failures. Loss of electrical connection would result in the loss of information from the instrumentation units. Since the primary information used in the control program is the cable lengths we could still safely retract the system and address the readout problem. We consider it highly unlikely for a cable to fail under the load of the calibration pole. The total mass of a 7 segment pole is about 5 kg, including the weighted segment is goes up to ~ 10 kg. The composite cable consists of 6 stainless steel cables. The cable clamps that connect the cable to the pole are double-sided cable clamps for reduncy and safety.

3) **Position sensor system failures**

The position of the calibration pole is continuously monitored in real-time through the following set of information:

1. cable lengths (primary information used in control software)
2. motor encoding (cross check to cable lengths)
3. pressure sensors (depth information)
4. tilt sensors (orientation of pole)
5. imaging of LEDs with CCD camers
(under development, this may or may not be real-time)

In addition to this instrumentation the cable will be marked in intervals of ~1m. This will allow us to manually determine the cable position and retract it by hand if it became necessary. In an emergency situation, a number of LED light sources that are installed in the KamLAND detector can be turned on to illuminate the inside of the ballon. This may allow us to see a visual image of the calibration pole on one or several of the CCD cameras that are permanently installed in the detector. If the encoder pulleys fail and we loose information about the cable lengths information #3-5 can be used to return the calibration pole into a vertical, neutral position and to retrieve it from the detector.

4) **Pivot Block ("top-of-the-triangle") clamp failure**
(the one that attaches to one of the cables and allows the other cable to slide)

The clamp that forms the triangle of the control cables is the pivot block. The sliding part is made of Teflon. It is designed to minimize/eliminate the possibility of the sliding cable getting stuck. For pictures of the part see:
http://kmheeger.lbl.gov/kamland/4pi/pics/parts/parts-Pages/Image60.html
http://kmheeger.lbl.gov/kamland/4pi/pics/parts/parts-Pages/Image61.html
http://kmheeger.lbl.gov/kamland/4pi/pics/parts/parts-Pages/Image62.html
http://kmheeger.lbl.gov/kamland/4pi/pics/parts/parts-Pages/Image63.html
http://kmheeger.lbl.gov/kamland/4pi/pics/parts/parts-Pages/Image64.html
http://kmheeger.lbl.gov/kamland/4pi/pics/parts/parts-Pages/Image65.html
In all of the test deployments we have performed with this version of the pivot block we have never seen the cable getting stuck. If the sliding cable were to get stuck and started lifting the entire assembly of the calibration pole the torque limit of the motor system for the sliding cable might trip and automatically shut down the drive. It depends on the torque limit settings for each motor. We plan to have a table of torque limit settings for different pole configurations. In addition, after a short distance (< 10 cm in the vertical direction) when the depth readings of the pressure sensors at either end of the pole disagree with the calculated pole position based on the cable lengths the interlock of the control software would stop further motion. From the position of the calibration pole inside the detector we could infer that that the cable had become stuck in the pivot block. In this worst case scenario we would likely turn off the HV in the detector, turn on the fixed, peripheral LED lights in KamLAND, and try to get a visual image of the calibration pole with the existing CCD cameras. I imagine that we would try to alternate motions with each cable to loosen the pivot block. If it is possible to lower the pole into the vertical, neutral position we would do so and then retrieve the system for inspection and repair. In none of the testing we have done to date, we have seen the cable get stuck in this design of the pivot block.

Another unlikely failure mode is for the pivot block to come loose and slide on the cable. We have never seen this happen either. The pivot block is held with a solid stainless steel cable clamp. The clamp is secured with a set screw which prevents accidental loosening of the cable clamp. (Note to 4pi group: We should consider adding a latch to the cable clamp of the pivot block so that it can never fall off the cable even if the clamp came loose and started sliding.) As before, in this worst case scenario we would likely turn on the lights in the detector and have direct visual monitoring of the system before moving it any further. Unlike a cable getting stuck in the pivot block, a sliding pivot block would always allow us to return to the vertical, neutral position and retrieve the system.

5) **pole/calibration source system failure**

The calibration sources (Ge, Zn, Co) used with this system are all non-triggered radioactive sources. They are doubly encapsulated and certified by the calibration group of the KamLAND collaboration through a series of pressure and soak tests. The calibration sources

are attached using a standardized threaded mount and secured with an additional locking pin. The locking pin is usually tethered to the source mount with a nylon lanyard. The Co-60 sources that are to be used in the pole segments are doubly encapsulated and mounted inside thee pole segment with a push pin. This push pin can be tethered to the pole segment using a nylon lanyard. See the following pictures:
http://kmheeger.lbl.gov/kamland/4pi/pics/parts/parts-Pages/Image43.html
http://kmheeger.lbl.gov/kamland/4pi/pics/parts/parts-Pages/Image46.html

6) **software/control system failure**

Different failure modes of the electronics, control systems, control software and the computer systems have been anticipated and tested at Berkeley. A UPS provides backup power for 50min for the entire system. The data from the control software is logged in a data base and can be re-loaded after an unexpected system crash or shutdown. For more information see:
http://kmheeger.lbl.gov/kamland/4pi/reviewjune05/4pi_control_failure_modes.pdf
http://kmheeger.lbl.gov/kamland/4pi/reviewjune05/4pi_emergencyrecovery.pdf

7) kind of a catch all - small parts, connectors, fasteners, etc.

Two types of tools are used for the assembly of the calibration pole: a special wrench to tighten the BTC coupling and a tool with carabiner for the extraction of the Co-60 sources. Both of these tools are permanently tethered in the glovebox. In addition, we have two push pins for use with the pin block. These push pins are also tethered in the glovebox.

The rotating pin block is permanently attached to the mounting flange for the 6" opening. The flange+pin block can be removed together through the transfer box when they are not in use for the off-axis calibration. The storage block for the Co-60 sources is large enough that it won't fit through the opening of the pin block when it is in place. The nylon cable guide is also oversized and will not fit through the opening of the pin block.

The pivot block consists of two pieces, the clamp part and the cable guide part. When assembled the pivot block won't fit through the opening of the pin block. The pivot block is taken apart and attached to the cables when the pin block opening is covered with the nylon cable guide. See the following photograph:
http://kmheeger.lbl.gov/kamland/4pi/pics/parts/parts-Pages/Image57.html
In this situation none of the two parts of the pivot block can fall into the detector.

The Co-60 sources inside each one of the pole segments are held in place with push pins. See the following photographs:
http://kmheeger.lbl.gov/kamland/4pi/pics/parts/parts-Pages/Image43.html
http://kmheeger.lbl.gov/kamland/4pi/pics/parts/parts-Pages/Image46.html
They have a key ring on one end and can be tethered to the pole segment with nylon string. A nylon lanyard is used as a backup line to the locking pin for all calibration sources. This is a well established technique. The nylon string is in hand at KamLAND.

II. Human Safety

1) Mechanical hazards (sharp objects, things dropping and hitting someone, gears and things that grab, etc)

The KamLAND 4pi source deployment system is located inside the glovebox. The motors are operated through either a manual control panel in the calibration tent or a computer control interface. During the assembly phase of the calibration pole one or two of the operators will have their hands inside the glovebox while one or both of the motor spools are operated. In this phase only the manual control is used. To move the motors and spools with the manual control pane requires a third person to continuously press a button on the manual control panel. Simply releasing this button will stop the motors. In addition, the manual control panel has an emergency stop button which will shut down the motor drives and controllers. For a picture of the manual control panel see:
http://kmheeger.lbl.gov/kamland/4pi/pics/album/album-Pages/Image1.html

In addition, an electronic motor torque limit is in use. It is currently set so that it can barely lift the full-length calibration pole. If the calibration pole or the spools got stuck the torque limit would shut down the drive and prevent the motor from overheating or damaging the motor+gears+spool assembly. If an operator's hand or a tool would obstruct the motion of one of the spools the motors would automatically shut down when the torque limit is exceeded.

There are no sharp objects in use inside the glovebox. All tools and parts are designed to be used with the viton gloves of the glove box.

For the assembly and operation of this system the operators stand inside the calibration tent on top of the calibration deck in front and on the back of the glovebox. For a picture of the calibration deck and the calibration tent see page 9 of the following file:
http://kmheeger.lbl.gov/kamland/4pi/reviewjune05/KamLAND4pi_LBNL_review.pdf
This is similar to the operation of the existing z-axis calibration system. The 4pi deployment is completely inside the glovebox. Therefore, there is no risks of parts dropping and hitting personnel during the operation of the 4pi systen.

2) Electrical/shock hazards

The electronics, controls, and power supplies for the 4pi calibration system will be located in a separate room – called the high voltage room – where all other HV supplies for the KamLAND detector are located. Cables made from commercial cable and wiring will connect the controls and electronics to the feedthrough plate of glovebox. All cables are shielded and grounded according to good electrical wiring practice. The signal and power lines for the motors and the instrumentation unit are brought in and read out through a special feedtrough plate in the glovebox. For a picture see page 84 of the following file:
http://kmheeger.lbl.gov/kamland/4pi/reviewjune05/KamLAND4pi_LBNL_review.pdf
External power cables are Belden PN 29501. Connectors and feedthroughs are Ceramaseal 18093-05-W. The cable from the glovebox feedthrough plate to the inside of the glovebox is custom: It consists of 16 AWG wires (1 size larger than standard for power). Custom connectors are used on one end, the other end uses Ceramaseal MS 3456LS14S-6S with backshell. The cables inside the motor vapor enclosure are made from the original Parker

cables PN 25GS cable 10.

All glovebox connections are Ceramtec weld-in feeldthroughs in a stainless steel plate Inside the glovebox special cables made out of Teflon wire with connectors from approved materials connect the signal and low-voltage power lines. For the motor power a commercial, voltage-rated cable is used. This cable is enclosed in viton heat shrink to make it compatible with the liquid scintillator vapors inside the glovebox.

In addition to the insulation of the cables the operator is insulated from the electrical cable and connections through the viton gloves of the glovebox.

No connections in this system are bare or exposed, and there is no risk of electric shock.

(We note that the system will be reviewed for electrical safety by the fire station in Mozumi, Japan, before installation in the KamLAND detector.)

1) **Fire/smoke/oxygen deficiency hazards**

Fire Hazard: The 4pi deployment system is operated inside the glovebox. The glovebox is continuously flushed with nitrogen during the operation of the system. The deployment system is designed and fabricated from approved materials (stainless steel, Teflon, nylon, gold, lucite) to withstand the interaction with liquid scintillator vapor. The motor and gear assembly is enclosed in a vapor-tight stainless steel enclosure that prevents liquid scintillator vapor from interacting with the motors and gears. Weld-in feedthroughs, teflon cables, and connectors made from approved materials are used to make the electrical connections inside the glovebox between the motor enclosure and the external feedthrough plate of the glovebox. All electrical cables are covered in Teflon insulation. All custom made connectors are enclosed with a nylon cover. For pictures of the in-glovebox cabling and nylon covers see page 82 of the following file :
http://kmheeger.lbl.gov/kamland/4pi/reviewjune05/KamLAND4pi_LBNL_review.pdf

The operating temperature of the motors and motor cover was measured during operation and found to be consistent with room temperature. There is no risk of igniting the liquid scintillator vapor from the motor operation.

An electronic torque limit (current limit) is used in the motor control system. This limit can be set by the expert user and is currently chosen so that the system can barely lift the calibration pole. Any usual resistance to the calibration pole, the cables, or spools will trigger the limit. This limit will also prevent the current in the cables from exceeding normal values. There is no risk of electrical fires.

Smoke/Oxygen Deficiency Hazard: During the assembly of the 4pi system the operators will be inside the calibration cleanroom on top of the calibration deck. This tent has a separate supply of radon-free air. The oxygen levels in the mine are generally monitored. (Note to the 4pi group: As calibration personnel will be in the calibration tent for prolonged periods of time we should consider the installation of an audible alarm when the oxygen level goes below a specified safe limit.)

4) Radiation hazards

The calibration sources to be used with this system are radioactive sources (^{68}Ge, ^{60}Co, ^{65}Zn) These sources are already in use at KamLAND for calibration with the existing z-axis system. Calibration experts at KamLAND are trained in the use and handling of these sources. LBNL personnel involved in the handling of these sources usually has sealed-source training. The sources are rather weak with a typical source strength of ~200-500 Bq.

In addition to these existing sources we have ordered several weak 60-Co sources with a strength of 100 and 200 Bq respectively for use in the pole segments. These doubly-encapsulated sources are fabricated by AEA Technology (http://www.qsa.aeat.com/index.html) and shipped to the University of Alabama where they will be characterized and certified for use in KamLAND. They will then be shipped directly to Japan for use with the 4pi calibration system.

5) Laser or UV, etc. hazards

No laser or UV light sources are used in the system. The only light sources to be used inside the detector are 830nm IR LEDs that are integrated in the instrumentation package. The LEDs used are Hamamatsu L3989. The specifications of this LED are posted at the following URL: http://kmheeger.lbl.gov/kamland/4pi/instrumentation/LED/Hamamatsu_L3989-02.pdf

The light emission of these LEDs is incoherent with a total light output of typically 4-5 mW. This does not pose a risk to the human eye. In addition, we will have normal room lights outside the glove box for illumination of the glovebox during the assembly of the calibration pole.

Based on these questions I summarize the following action items for the KamLAND 4pi group:

1. add latch to pivot block to prevent it from falling off if clamp came loose
2. load test of pivot block on cable sample soaked with mineral oil
3. test torque limit on sliding cable (#2) with full-length pole if sliding cable got stuck in pivot block
4. test interlocks of software for mismatch between actual pole configuration and configuration entered in control software